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Collaborative Efforts Within the Key West Campaign Sea Test

February 1995

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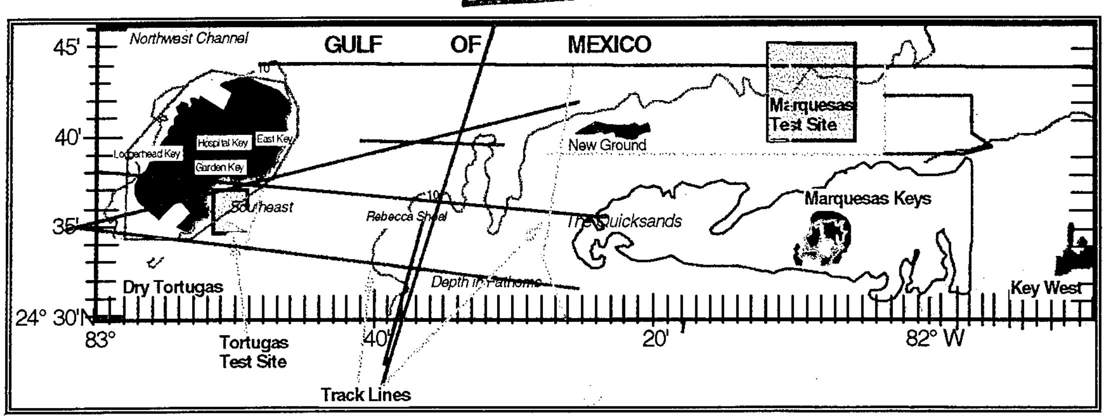

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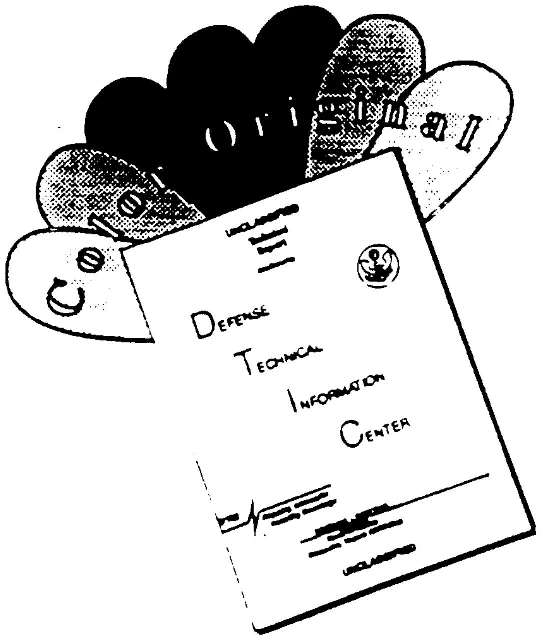

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13. ABSTRACT *(Maximum 200 words)*

During February 1995, four research vessels (WFS PLANET, R/V SEAWARD JOHNSON, R/V PELICAN, and R/V SEAWARD EXPLORER) and 115 scientists and technicians from five nations mounted a major scientific campaign in waters of the western Florida Keys. Scientific experiments during this Key West Campaign focused on the shallow-water carbonate sedimentary environments in the vicinity of the Marquesas Keys and the Dry Tortugas. This research is in keeping with the recent changes in strategic concept defined in the USN's 1992 paper "From the Sea" in which the focus of naval priorities has shifted from operations on the high seas to operations in the littoral regions of the world, where, Mine Counter Measures (MCM) are of critical importance. The Florida Keys provides the only environment in continental US waters which is analogous to the shallow-water tropical carbonate settings that are becoming increasingly important to naval operations (e.g., Persian Gulf) and where the biogeochemical processes that are typical of those carbonate environments can be studied. Teamwork among university and government laboratories, combined basic and applied research objectives, and international cooperation are all hallmarks of the Key West Campaign. In this report, objectives of participating programs, preliminary data from selected scientific instrumentation, and benefits to MCM operations are highlighted.

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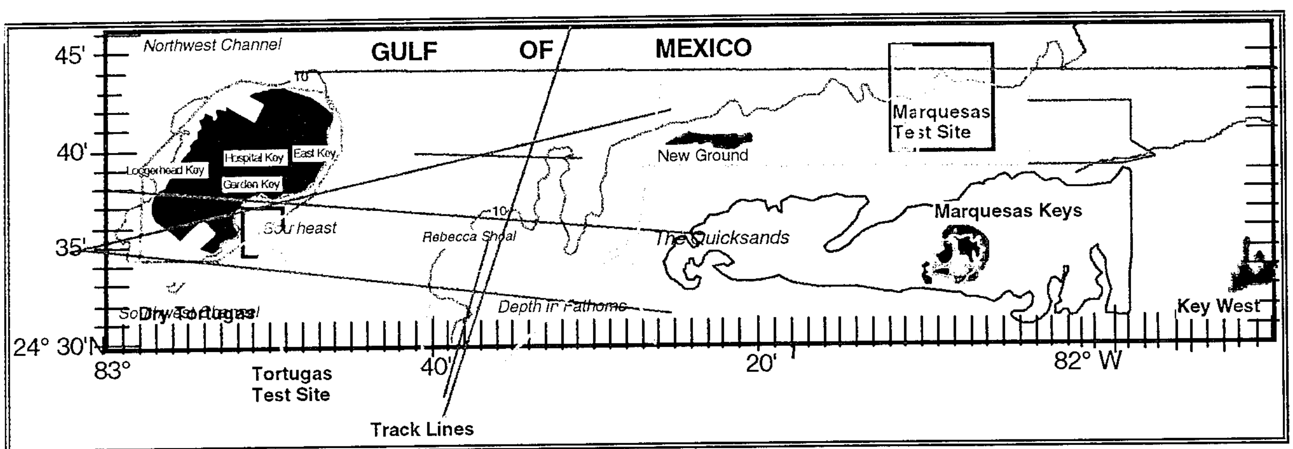

Figure 1. Key West Campaign Study Area; including track lines profiled by the nine sediment classification systems and location of the Dry Tortugas and Marquesas experimental sites. Extensive track lines within the Dry Tortugas and Marquesas are not shown.

BACKGROUND: During February 1995, four research vessels (WFS PLANET, R/V SEWARD JOHNSON, R/V PELICAN and R/V SEAWARD EXPLORER) and 115 scientists and technicians from five nations mounted a major scientific campaign in waters of the western Florida Keys. Scientific experiments during this **Key West Campaign** focused on the shallow-water carbonate sedimentary environments in the vicinity of the Marquesas Keys and the Dry Tortugas **(Figure 1)**. This research is in keeping with the recent changes in strategic concept defined in the USN's 1992 paper

"...From the Sea" in which the focus of Naval priorities has shifted from operations on the high seas to operations in the littoral regions of the world, where, Mine Counter Measures (MCM) are of critical importance. The Florida Keys provides the only environment in continental US waters which is analogous to the shallow-water tropical carbonate settings that are becoming increasingly important to naval operations (e.g. Persian Gulf) and where the biogeochemical processes that are typical of those carbonate environments can be studied. Teamwork among university and government laboratories, combined basic and applied research objectives, and international cooperation are all hallmarks of the Key West Campaign. In this report, objectives of participating programs, preliminary data from selected scientific instrumentation, and benefits to MCM operations are highlighted.

EXPERIMENTAL OBJECTIVES: The experiments that made up the Key West Campaign were supported by numerous programs that crossed the barriers of applied and basic research **(Figure 2)**. Central to the experiments was the Office of Naval Research's (ONR) Coastal Benthic Boundary Layer (CBBL) program (Michael Richardson, chief scientist). This basic research program is directed towards the physical characterization and modeling of benthic boundary layer processes and the impact that these processes have on seafloor properties that affect shallow-water naval operations. Of particular interest during the Key West Campaign, were the effects of biogeochemical processes (mineralization, cementation and dissolution) on surficial sediment diagenesis. Naval Research Laboratory (NRL) core programs in sediment geoacoustic properties and sediment geochemistry also contributed to the basic understanding of environmental processes in this unique environment. The CBBL and NRL experiments provided a unique opportunity for more applied programs to address issues such as mine burial, sediment classification technologies, high-frequency bottom-interacting acoustics, and prediction of seafloor engineering properties in a well-understood and characterized environment.

The Technical Cooperation Program (TTCP: Samuel Tooma, coordinator) took advantage of this well-classified sedimentary environment and the infrastructure provided by the CBBL to test the current international state of technology for acoustic remote classification of sediments. The following eight systems were tested: RoxAnn (UK); Datasonics First Generation Chirp Seafloor Profiling System (UK); QT (Quester Tangent) C-VIEW Bottom Classifier (Canada); Sediment Density

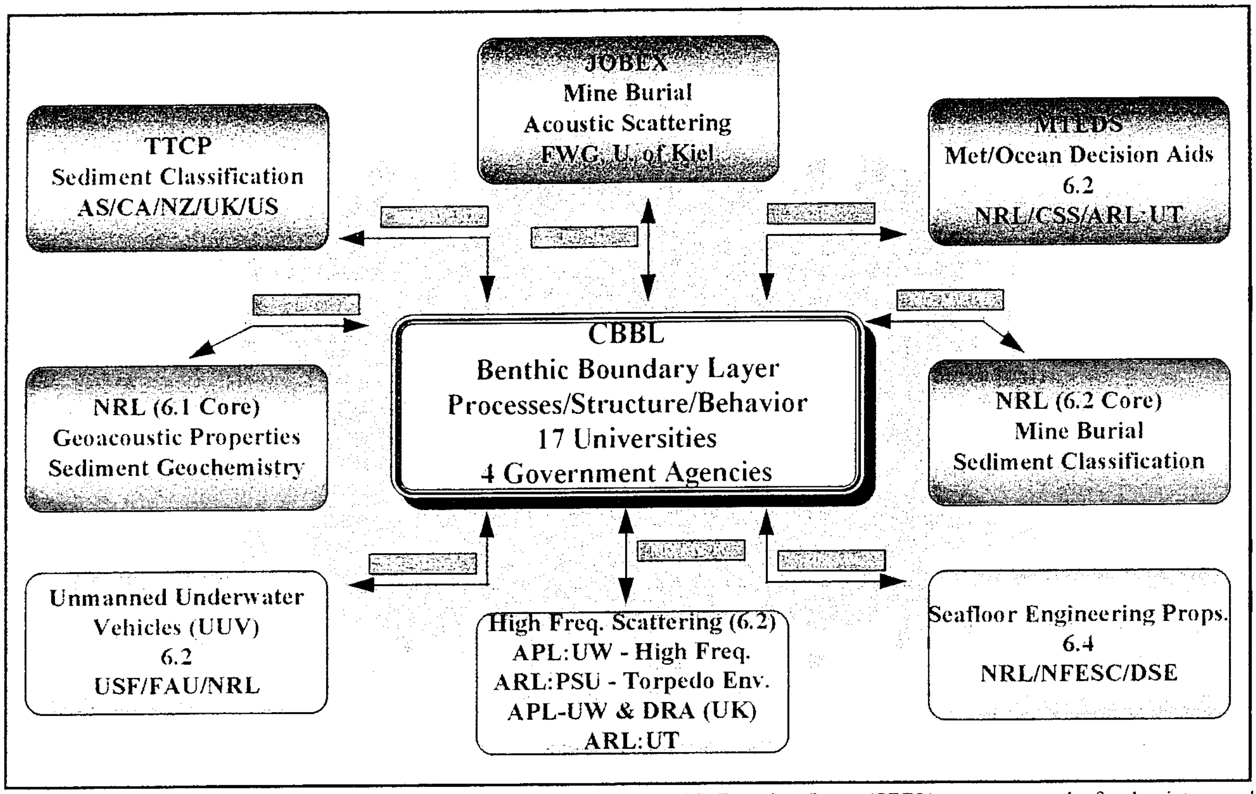

Figure 2. Programs comprising the Key West Campaign. The Coastal Benthic Boundary Layer (CBBL) program was the focal point around which the other participating programs revolved. The Technical linkages between CBBL and these programs are abbreviated. They are: MV - Model Verification; MD - Model Development; PU - Physical Understanding; and SD - System Development. The term 6.1 refers to Basic Research; 6.2 years refers to Exploratory Development (i.e., more applied than basic research); and 6.4 refers to Engineering Development.

Profiler (NZ); Acoustic Seafloor Classification System (US); Full Spectrum Chirp Sonar (US); Multichannel Seismic Profiler (UK); and Quantitative Side Scan Sonar (Germany). Co-located measurements were made over a variety of sediment types (muds, loose and hard-packed sands, coral rubble, and live reefs). Most ground truth data collection was supported by CBBL and the University of South Florida Unmanned Underwater Vehicle (UUV) Remote Sensor programs. Accurate remote classification of sediment properties is important for development and performance prediction of high-frequency acoustic systems used for detection and classification of bottom mines and for prediction of mine burial.

The Key West Campaign provided a unique opportunity to demonstrate the MCM Tactical Environmental Data System (MTEDS) (Samuel Tooma and Dan Lott, coordinators). MTEDS is designed to demonstrate the potential for an MCM ship to have and use an on-board capability to make environmental measurements for input into system performance prediction models and/or real-time tactical decision aids. Important aspects are that

environmental measurements must be made in situ, while underway, ported in real time to a Navy standard desktop workstation, stored in a data management system, displayed on the workstation CRT, and available as inputs to resident algorithms designed to provide MCM tactical information.

Potential for remote characterization of sediment engineering properties was studied by a joint program among NRL, Naval Facilities Engineering Service Center (NFESC), and Defense Science Establishment (DSE) of New Zealand. NFESC measured in situ strength-related engineering properties using a piezocone tripod (penetration resistance and pore pressures) and expendable doppler penetrometer (shear strength). Continuous profiles of sediment density were measured with the New Zealand broadband sediment density profiling system and point measurements of sediment penetration resistance were made with the New Zealand Electronic Sediment Strength Probe. Measured engineering properties will be compared to the results of laboratory testing of strength-related properties and to predictions generated by the various acoustic and electrical remote sensing systems.

The cooperative program among the University of South Florida (USF), Florida Atlantic University (FAU), and NRL "Sediment Characteristics of Selected Coastal Environments" used the opportunity to develop and improve inversion techniques for normal incidence sediment classification systems used to remotely determine sediment physical and geoacoustic properties. This project's goal is to determine mechanisms responsible for high frequency acoustic scattering. The FAU Full Spectrum Chirp Sonar sediment classification system will ultimately be a part of the UUV being developed by USF for MCM applications.

The Joint High-Frequency Backscattering Experiments (JOBEX) program, supported by Forschungsanstalt der Bundeswehr für Wasserschall- und Geophysik (FWG), included backscattering strength measurements using a 100 kHz quantitative side-scan sonar. These data were used to select the Key West Campaign study sites and to provide needed quantitative acoustic bottom scattering measurements from a variety of carbonate sediments. Experiments were performed to study long- and short-term mine burial in carbonate sediments.

High-frequency scattering measurements were supported by CBBL, MTEDS, Torpedo Environments, High-Frequency Acoustics, and Ocean Acoustics programs, as well as by the UK

Defense Research Agency (DRA). Measurements were made from R/V SEAWARD EXPLORER using the APL/UW BAMS tower, a spar buoy with two transmitters, a Mk 46 sonar head, and two broadband transmitter/receiver arrays operated by DRA; from WFS PLANET using the German quantitative side scan sonar; and from R/V SEWARD JOHNSON using a remotely-operated vehicle (ROV) designed by ARL/UT. Scattering data (forward, back, and out-of-plane) were collected from the air-water and sediment-water interfaces over frequencies ranges commonly used by MCM forces. The abundant seafloor and water column environmental data collected during the experiments will be used to improve understanding of scattering mechanisms and to validate/develop new acoustic scattering models.

The extensive measurement program with associated infrastructure presented the opportunity to conduct an initial mine burial experiment supporting an emerging program at NRL. The experiment was designed: (1) to assess our ability to predict impact burial depth into carbonate sediments; (2) to correlate reverberation statistics with percentage burial; (3) to investigate changes in reverberation as scour burial develops; and (4) to develop methodologies for use in subsequent mine burial experiments.

SUMMARY OF DATA COLLECTED AND EXPERIMENTS: The campaign was highly successful with over 1300 nm of acoustic lines, nearly 500 core and grab samples, and 100 man-hours diving. The following provides a summary of the extensive sampling conducted as well as the diversity of innovative technologies used to characterize magnitudes and rates of environmental processes, and to measure sediment structure, properties, and behavior.

Over 350 hours of acoustic profiling was completed during the Key West Campaign from the R/V SEWARD JOHNSON, R/V PELICAN and WFS PLANET. Acoustic sediment classification systems included the High Resolution Acoustic Seafloor Classification System (ASCS); RoxAnn; QT C-VIEW Bottom Classifier; Datasonics Chirp Sonar; Full Spectrum Chirp Sonar; modified Klein quantitative side scan sonar; a multichannel subbottom reflection profiling system; and Sediment Density Profiler **(Table 1).** The primary purpose of each of these systems is to provide bottom and/or subbottom characterization of sediment physical/ geotechnical properties. Acoustic signals used to characterize sediment properties included both narrow and wide beam single frequency and FM

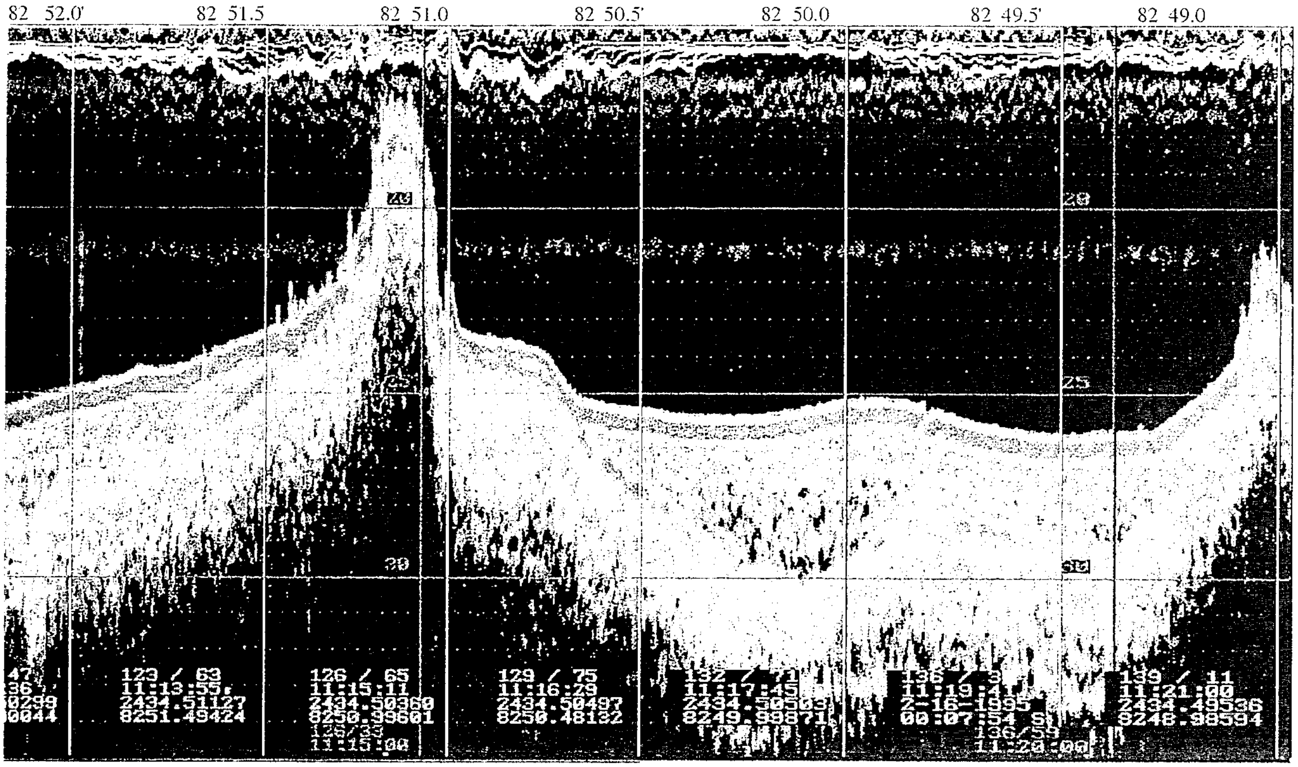

Figure 3. This illustration depicts a 3 nmi long east-west 4 kHz high resolution seismic record across southern portion of the Dry Tortugas CBBL Test Area at 24° 34.5'N latitude. Hot colors (red, yellow, etc.) below the sediment-water interface indicate high reflectivity from sand, coral and rock. Cool colors (blue, green, brown, etc.) indicate low reflectivity or soft muddy sediments. The major sediment structure in this illustration is the Key Largo Limestone formation which is shown as the continuous red/yellow irregular undulating reflector located 1 - 4 m below the sediment surface. It is exposed at the seafloor surface in the left center and far right portions of the record where it forms the vase of present day live reefs. In the right center, it underlies a large sediment pond of soft carbonate muds. The sediment deposited over the Key Largo Limestone is mostly carbonate mud that grades to sand west of the reef. Sediment thickness varies from near zero at the reefs to 4 m in the sediment pond. The fuzzy looking structures (lt. blue color) above the reefs are due to sea fans, corals, and gorgonians.

sweeps covering the frequency range of 400 Hz to 200 kHz. These acoustic signals were generally received in normal incident mode. However, one side scan and one multi-channel array system were deployed. Both surface and subbottom properties were estimated using a variety of physics-based and/or empirical-based inversion techniques. A 5 km x 5 km area southeast of the Dry Tortugas was extensively surveyed using the FWG 100 kHz side-scan sonar with a 3.5 kHz subbottom profiler, and the NRL ASCS. The data sets collected by these systems were used to construct a surface sediment character map and to measure sediment depths within the primary CBBL study area. These maps were used to select a uniform area for the main experiment and to provide a guide and extensive ground truth for the sediment classification trials.

Over 1300 nm of acoustic tracks were run with

TABLE 1. SEDIMENT CLASSIFICATION SYSTEMS USED DURING THE KEY WEST CAMPAIGN

SYSTEM NAME	FREQUENCIES	PREDICTED PROPERTIES	MEASUREMENT TECHNIQUES	ANALYSIS THEORY	SYSTEM USER
ROXANN	24 & 200 kHz	SURFACE SEDIMENT TYPE	VERT. INCIDENCE ACOUSTICS A & B ARRIVALS	DIFFERENCE ANALYSIS BTWN RETURNS A & B	DRA - UK
DATASONICS 1ST GEN. CHIRP	2.0 - 10 kHz	SURFICAL SEDIMENT TYPE	VERT. INCIDENCE FM SWEEP	AMPLITUDE OF SEAFLOOR REFLECTION	DRA - UK
SEDIMENT DENSITY PROFILER	0.6 - 15 kHz	SEDIMENT DENSITY PROFILE	VERT. INCIDENCE ACOUSTICS	ECHO DECONVOLUTION; MULTI-LAYER INVERSION	DSE - NZ
QT C-VIEW BOTTOM CLASSIFIER	24 - 200 kHz	SURFACE SEDIMENT TYPE	VERT. INCIDENCE ACOUSTICS	PRINCIPAL COMPONENT ANALYSIS & 3-D ANALYSIS TECHNIQUES	EDRD - CA
ASCS	4,12,15, & 50 kHz	SEDIMENT TYPE & PROPERTIES WITH DEPTH	NARROW BEAM VERT. INCIDENCE ACOUSTICS	MULTI-LAYER INVERSION	NRL - US
FULL SPECTRUM CHIRP	SYS-A - 1.5 - 15 kHz SYS-B - 0.5 - 12 kHz	SEDIMENT PROPERTIES WITH DEPTH	VERT. INCIDENCE FM SWEEP W/PLANAR RECEIV ARRAY	ATTENUATION VOL. SCATTERING, REFLEC. AMPL., & PHASE INVERSION	FAU - US
MULTI-CHANNEL SEISMIC PROF.	0.4 - 10 kHz	SUBBOTTOM DENSITY/VEL. PROFILE	MULTI-CHANNEL REFLECTION	INVERSION FOR GEOTECHNICAL PROPERTIES	UWB - UK
QUANT. SIDE SCAN SONAR	100 kHz	SEDIMENT BACKSCATTER STRENGTH	SIDE SCAN ACOUSTIC BACKSCATTER	CALIBRATED BACKSCATTER STRENGTHS	FWG - GER

the acoustic systems in the Dry Tortugas test area, north of the Marquesas Keys, and near Rebecca Shoals (**Figure 1**) in many cases systems were operated simultaneously. **Figure 3** presents a seafloor classification profile collected by the NRL ASCS system within the Dry Tortugas test area.

Sediment ground truth was provided by direct collection of sediments, in situ measurements of sediment properties, and various visual techniques. A total of 155 gravity cores, 11 vibracores, 66 diver-collected cores, 208 box cores, and 28 grab samples provided ample sediment material for study. Sediment geoacoustic (compressional and shear wave velocity and attenuation), physical (porosity, water content, bulk density, grain size), and geotechnical (strength-related) properties were determined at sea or at shore-based facilities. More extensive geotechnical testing (triaxial stress-strain behavior, consolidation behavior, and permeability) will be completed at various investigators' facilities. In situ geoacoustic, geoelectric, and geotechnical properties were measured using a variety of specialized techniques (**Table 2**). These unique systems deployed at 153

TABLE 2. SUMMARY OF DIRECT IN SITU MEASUREMENT TECHNIQUES USED DURING THE KEY WEST CAMPAIGN

SYSTEM NAME	MEASURED PROPERTIES	MEASUREMENT TECHNIQUES	ANALYSIS THEORY	SYSTEM USER
ACOUSTIC LANCE	COMPRESSIONAL WAVE VELOCITY AND ATTENUATION	HYDROPHONE TRANSMITTER AND RECEIVERS	FULL WAVEFORM DOWNCORE LOGGING (1-10 KHZ)	R.H. WILKENS, U. HAWAII
MAGIC CARPET SYSTEM #1	SHEAR WAVE VELOCITY	ELECTROMAGNETIC SEISMIC SOURCE WITH GEOPHONE ARRAY	TRAVEL-TIME INVERSION (REFRACTION THEORY)	A.M. DAVIS, U. WALES, BANGOR
MAGIC CARPET SYSTEM #2	SEDIMENT ELECTRICAL PROPERTIES	FOCUSED ELECTRODE PAD	RESISTIVITY	A.M. DAVIS, U. WALES, BANGOR
DIAS	SHEAR MODULUS	DUOMORPH PROBES	ENERGY DAMPING	D.L. LAVOIE, NRL
GEOACOUSTIC PROBES (ISSAMS; NEPTUNE; GISSAMS)	COMPRESSIONAL AND SHEAR WAVE VELOCITY AND ATTENUATION	PIEZOCERAMIC CYLINDERS AND BIMORPH CERAMIC BENDERS	PULSE TECHNIQUES (TIME OF FLIGHT)	M.D. RICHARDSON, NRL
EXPENDABLE DOPPLER PENETROMETER	SHEAR STRENGTH AND RELATIVE DENSITY PROFILES	HIGH-FREQUENCY DOPPLER SHIFT DURING SEAFLOOR PENETRATION	DECONVOLUTION OF PENETROMETER DECELERATION	H.G. HERMANN, NFESC
PIEZOCONE	SHEAR STRENGTH, SEDIMENT TYPE AND PERMEABILITY	QUASI-STATIC CONE PENETROMETER WITH FRICTION SLEEVE AND PIEZOMETER	CONE TIP BEARING CAPACITY, FRICTION/DRAG ON SLEEVE AND PORE PRESSURE DISSIPATION	H.G. HERMANN, NFESC
ELECTRONICALLY INSTRUMENTED PENETROMETER	DYNAMIC BEARING STRENGTH	PROBE ACCELERATION	ACCELERATION VS DEPTH TO YIELD FORCES ON PROBE, INCLUDING HYDRODYNAMIC DRAG	R.B. HURST, DRE, NZ
DIVER VANES	VANE SHEAR STRENGTH	IN SITU DIVER OPERATED VANE	VANE RESISTANCE	K.B. BRIGGS, NRL
PIEZOMETER	AMBIENT AND DYNAMIC PORE PRESSURES	DIFFERENTIAL VARIABLE-RELUCTANCE-TRANSDUCERS	DISSIPATION AND FLUCTUATION OF PORE PRESSURES	R.H. BENNETT, NRL

sites provided spatial variability, including depth profiles, of shear and compressional wave velocity and attenuation, shear modulus, bulk density, sediment strength (penetration resistance, dynamic bearing capacity, and vane shear strengths), ambient and dynamic pore pressures, permeability, and electrical resistivity. These data, combined with extensive laboratory measurements, will provide a unique opportunity to compare sediment geoacoustic, physical, and geotechnical property predictions collected with remote acoustic systems to laboratory and in situ ground truth.

Divers made 82 dives to deploy in situ probes, collect cores, take still and video camera pictures of bottom morphology, measure roughness, determine percentage and rates of mine burial, and conduct seafloor experiments where bottom roughness or structure was manipulated. More than 50 observations of bottom characteristics, bottom roughness, and mine burial were made with diver-operated still and video cameras and by surface-operated cameras. These data will be used to test high-frequency bottom scattering and mine burial models.

An instrumented tetrapod was successfully deployed from the R/V PELICAN in the Southeast Channel of the Dry Tortugas in 26.2 m of water. The tetrapod was deployed immediately prior to the passage of an intense frontal system. Diver observations immediately following the passage of the front revealed that the seabed was mantled by a fluff layer, about 5 cm thick, that disappeared by the end of the deployment three weeks later. Hourly measurements were made of bottom water current velocity using Marsh-McBirney electromagnetic current meters, turbidity using optical backscatterance sensors, bottom roughness using a digital sonar altimeter, temperature using digital thermistors, and sea level using digiquartz pressure sensors. The purpose of these tetrapod measurements was to characterize physical processes responsible for sediment erosion, transport and deposition.

Box core samples (208) were collected both in the Dry Tortugas and Marquesas experimental sites for radiological, biogeochemical, geotechnical and geoacoustic studies. Radiochemical measurements included rates of bioturbation and sedimentation. Biogeochemical measurements included measurements required to identify processes responsible for early sediment diagenesis (measures of sulfate reduction and sulfide oxidation, stable isotopic ratios, pore water chemistry, carbonate mineralogy and microscopic, and stable carbon isotopic evidence for carbonate cementation). Geotechnical and geoacoustic measurements, including physical properties, shear and compressional wave velocity and attenuation, shear modulus, and shear strength, were made in order to characterize the sediment properties and will be used as model inputs for acoustic prediction purposes. Data from these studies will provide: (1) an understanding of the effects of environmental processes on sediment structure; (2) a quantification of sediment structure from micron to centimeter scales; and (3) a measure of sediment behavior under various stress-strain conditions.

Experiments on mine burial by impact, scour, and sand ridge migration were conducted from the WFS PLANET and R/V SEAWARD EXPLORER. Fourteen short-term impact burial trials were made using the FWG burial-recording mines, and long-term scour burial studies were conducted with six mine types either within or near the acoustic field of view of the APL/UW BAMS tower. Mines within the BAMS field of view (MK 42, MK 82, MK 52, Manta, German burial-recording) were also subjected to target scattering studies using both BAMS and FWG's quantitative side-scan sonar. Attempts were made to correlate reverberation statistics with scour around the mines. Divers made numerous visual and photographic observations in an effort to document mine scour. Two FWG burial-recording mines were also deployed near Rebecca Shoals to study mine burial by sand ridge migration.

In meeting the MTEDS objectives, 27 track lines covering 108 nm were run within the Dry Tortugas grid area. During these runs, the following data sets were collected in situ at ship transit speeds of 4-5 knots, stored in the MTEDS data base, displayed on the workstation's screen, and used to make such predictions as percent mine burial: (1) bathymetry; (2) current velocities collected with an Acoustic Doppler Current Profiler; (3) sediment classification data from the ship's fathometer and NRL's ASCS; and (4) differential GPS navigation. In addition, the following recorded data sets were re-played into the MTEDS data base: (1) high-frequency acoustic reverberation data collected with an AN/SQQ-32 mine-hunting sonar; (2) sound speed profile data computed from conductivity, temperature and depth collected by ARL/UT with the Aqua Shuttle excursion device; and (3) conductivity, temperature, and depth data collected with a CTD. Results from this demonstration have proven the MTEDS concept.

Bottom scattering measurements were made approximately once per hour for 16 days from the R/V SEAWARD EXPLORER using the APL Benthic Acoustic Measurement System (BAMS), an autonomous bottom-mounted tripod. The circularly scanning 40 kHz and 300 kHz sonars have resolutions of about 5 m x 5 m and 1 m x 1 m respectively within the 50 m radius scan. The BAMS data can be processed to produce images of scattering strength (Lambert parameter), bathymetry, and correlation between scans. An example image, showing bathymetry, is shown in **Figure 4**. Correlation of successive scans shows changes in acoustic scattering that can be related to the effects of environmental processes on sediment

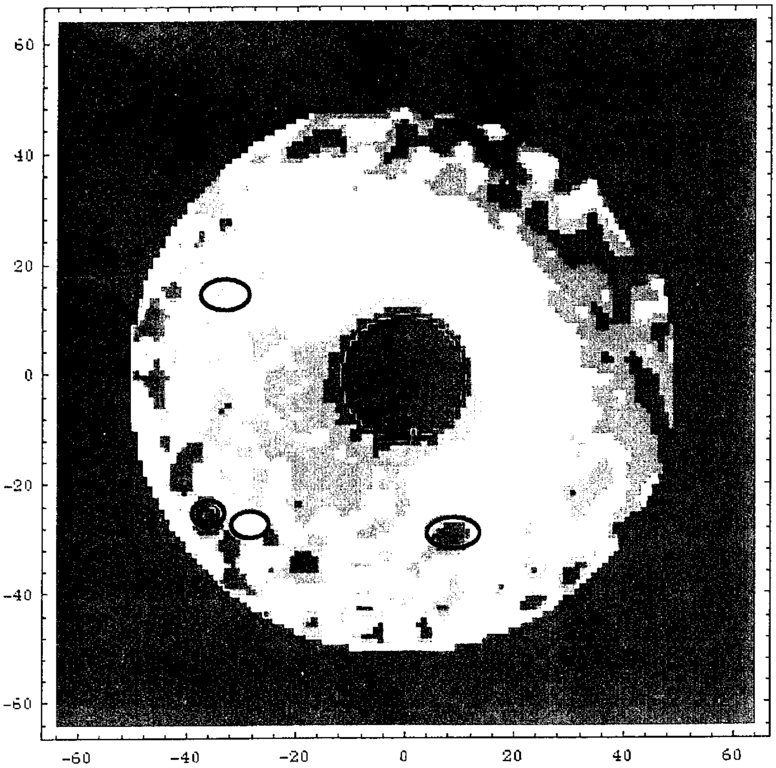

Figure 4. This example shows a bathymetry image of the bottom within a 50 m radius of the BAMS tower. It was made using BAMS 40 kHz transmitter and splitbeam receivers. The data lies in the annulus between the two black circles. Color progression is violet, blue, green, yellow, and red as one goes from a meter above to a meter below the feet of the tripod. The top marked ellipse surrounds a natural depression. That area was first discovered in images of scan-to-scan correlation where it showed up as a region of high decorrelation with time. Subsequent diver examination of the area showed it to be populated by finger sponges. The lower left pair of ellipses surround areas where divers altered the topography by digging a pit and building a mound of sediment. The lower right ellipse surrounds an area where a reference sphere was tethered above the bottom. Note also that the tower is slightly tilted relative to the mean level of the bottom as indicated by the general reddening as one goes from lower left to upper right (this was confirmed independently by the BAMS inclinometer).

structure. A total of 488 scans were made with the 40 kHz sonar and 45 scans were completed with the 300 kHz sonar. A subset of this data was uploaded via a surface link and processed on-board so that areas of rapid and slow decorrelation could be investigated by divers. Experiments were conducted within the BAMS field of view that included changing the large and small scale topography of the bottom and inserting mine-like objects. In addition, bottom bistatic scattering measurements were made using the BAMS 40 kHz sonar as a source and a steerable 1.5 m ship-deployed array as a receiver. Finally, combined surface/bottom bistatic scattering measurements were performed using the 1.5 meter steerable array in combination with a SPAR buoy instrumented with omni-directional transmitters and sea surface back-scatter measurements were carried out using a MK 46 sonar head.

The SEAWARD EXPLORER was also used in bottom backscattering and target strength

measurements made by DRA using two steerable transmitter/receiver arrays, one capable of operating from about 30 to 70 kHz and the other from about 100 to 200 kHz. The broad range of frequencies spanned by these sonars allows frequency dependence effects of both bottom and target scattering to be examined.

ARL/UT conducted 200 kHz bottom backscatter measurements over a variety of grazing angles using an ROV equipped with a modified obstacle avoidance sonar for generating the active pulse and measuring the resulting backscatter. The ROV was also equipped with a video camera for providing a video record of bottom type and conditions. Nine sets of backscattering measurements were made, two of them in the vicinity of the APL BAMS tower, thus allowing comparison with both BAMS data and the DRA measurements. The spatial distribution of bottom backscattering was also measured using FWG's quantitative side-scan sonar (100 kHz). Complete side-scan coverage of the 5 x 5 km area of the main experimental site (Dry Tortugas area) was achieved by 34 overlapping 200 m wide swaths. Data from the side-scan sonar were also digitized to allow quantitative estimates of bottom backscatter strength. In total, the bottom measurements covered the 30 to 300 kHz frequency range. The multiple platforms used within this frequency range allow comparisons that will test data quality.

IMPLICATIONS OF THE KEY WEST CAMPAIGN: The Key West Campaign was an extremely successful integrated experiment. All scientific and technical objectives were met or exceeded. The planned analyses of the resultant data sets will provide benefits, both to the scientific community, in terms of improved understanding of how environmental processes affect littoral carbonate environments, and to the naval community with improved operational capability.

VALUE TO SCIENTIFIC COMMUNITY: The Key West Campaign provides an excellent example of how an integrated program can provide the diverse range of data required to develop a detailed understanding of the natural environment and the understanding necessary to model the system in its entirety. Within the Key West Campaign, the approach adopted to achieve this objective was a multi-disciplinary one with researchers from several institutions combining their expertise and unique measurement capabilities to quantify the affects of physical, biological, and chemical processes on sediment structure, physical properties, and behavior. For example, the temporal and spatial variability of high-frequency acoustic scattering is

controlled by variations in bottom roughness and sediment physical properties. In Key West sediments, biological (sediment reworking) and physical processes (wave and tidal currents) have been shown to alter fine-scale bottom roughness on time scales of minutes to days, while biogeochemical processes have been shown to control the depth distribution of sediment physical and geoacoustic properties. Spatial and temporal variations in high-frequency backscatter strengths measured during the Key West Campaign appear to correlate with environmentally induced changes. Once sediment properties and behavior can be predicted under a set of environmental driving forces, environmental simulations can be made.

VALUE TO THE NAVY: The change of emphasis of naval operations from deep oceanic waters to shallow littoral regions, requires a greater knowledge of how environmental processes in these regions impact the performance of such naval systems as ASW and mine-hunting sonars and torpedo guidance and control. Naval systems, such as these, must be able to respond to these unique and dynamic environments in real time. An ability to predict the performance of these systems requires a greater understanding of the physics and modeling of benthic boundary layer processes. The Key West Campaign results will go a long way in allowing the Navy to better predict ASW system performance, mine hunting sonar performance for improved detection and classification of sea mines, mine burial probability, torpedo performance, and shock wave propagation and attenuation in very shallow water sediments. The latter is possible by improvement to shock wave propagation models based on sediment stress-strain relationships derived from sediment structure and fluid flow in a porous media. The results from the Key West Campaign will allow the Navy to define environmental system measurement specifications relative to remote acoustic and electromagnetic sediment classification and sediment engineering properties such as sediment strength needed for sea floor engineering projects and mine burial prediction. Other naval benefits that will result from the Key West Campaign include a capability to measure selected environmental parameters in situ and to use this data in real time to provide inputs for determining optimum sonar and torpedo systems mode settings as well as tactical utilization of available naval assets such as ships, helicopters, divers, and unmanned underwater vehicles. This capability addresses a stated NATO objective of rapid environmental assessment of a naval objective area.

WAY AHEAD FOR MARINE SCIENCE SEA TRIALS: Severe budget cuts and rising research ship costs are making marine science field experiments almost prohibitive. These trends are expected to continue. Thus, the time for stand-alone academic or Navy laboratory experiments with either basic or applied objectives is quickly becoming a thing of the past. Collaborative experiments similar to the Key West Campaign appear to be the way ahead for marine research. Another significant benefit resulting from this integrated approach is the establishment of professional collaborative relationships among universities and government institutions of several nations. This effort has already resulted in a cross fertilization of academic and Navy laboratory expertise, which in turn, has helped break down the wall between basic and applied research to the benefit of both communities. It is this sharing of scientific and ground truth data, ship costs, normal logistics costs, scientific equipment, and laboratory facilities that will be all the more common in the years to come. The benefits of these interactions are obvious: cheaper, more affordable research, better measurement systems, more complete data sets, more comprehensive research plans, more coincident data sets, integrated scientific papers, better attended and more fruitful workshops and symposia, and greater international cooperation.

PLANS FOR OUTYEARS. Data dissemination will begin with a special Key West Campaign preliminary results poster session (CBBL: Shallow-water Processes) of the 1st SEPM congress on Sedimentary Geology held at St. Petersburg Florida from 13-16 August, 1995. Dawn Lavoie (NRL) and Chuck Holmes (USGS) are co-chairing that session. Preliminary mine burial results were presented by Dan Lott to NATO's Mine Burial Specialist Team which convened at SACLANTCEN, La Spezia, Italy in May 1995.

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